10/582661
AP3 Rec'd PCT/PTO 12 JUN 2006
[10901/128]

SCANNING HEAD FOR OPTICAL POSITION-MEASURING SYSTEMS

The present invention relates to a scanning head for optical position-measuring systems. Such scanning heads are used to detect light modulated by a scale grating in a spatially resolved manner and to make available corresponding signals for the purpose of determining the position of the scanning head relative to the scale.

Position-measuring systems play an ever more important role in this increasingly automated world. They furnish the basis for exact positioning of drive systems in many applications, for instance, in the field of machine tools. The optical position-measuring systems described here are based on scanning a scale that has a measuring standard in the form of a line grating. The scanning head used for this includes a light source from which light falls on the scale graduation via a transmitting grating. After the interaction with the transmitting grating and the scale grating, the light has a spatial intensity pattern which is able to be detected in the scanning head using a receiving grating and is able to be used for position determination.

On this point, it is known that one may form a photodetector from a plurality of photosensitive areas. These photosensitive areas are situated in the scanning head in such a way that they are able to record the different phases of the intensity pattern and to supply corresponding electrical output signals. The individual, evenly spaced photosensitive areas form a receiving grating, in this context.

Preferably, four signals are generated that are offset by 90 degrees with respect to each other in each case, from which, in a sequential electronic system, counting signals connoted

with direction may be derived. For, in response to the shifting of the scale relative to the scanning head, the individual phase-shifted signals change as a function of position.

Usually, from the four output signals mentioned, first of all two signals shifted by 90 degrees with respect to each other and free from offset errors, amplitude errors and phase errors are synthesized, which are suitable for a finer subdivision and interpolation. The counting signals connoted with direction are able to permit therewith a substantially finer position determination than would be possible, for example, by counting the maxima and/or minima of the intensity pattern at the photosensitive areas of the scanning head.

For reasons described further on, it is advantageous if the individual photosensitive areas are as near as possible to one another. The use of discrete component parts, such as photodiodes, limits, in this case, the possible miniaturization of the photodetectors. Therefore, structured photodetectors have been implemented which, using customary process steps of microelectronics, permit the production of structured, photosensitive areas on one single semiconductor substrate.

Because of the low inclination to cross feed between the individual photosensitive areas, in this context, there is available, above all, the technologically well manageable amorphous silicon (a-Si), whose use for converting light to electric current is known, for instance, from the solar cell field.

DE 10129334 A1 describes an optical position-measuring system having a light-receiving device based on the principle described above. The photosensitive areas for scanning of

locally intensity-modulated light of different phase positions are constructed as receiving gratings in the form of several semiconductor layer stacks of doped and undoped amorphous silicon. The construction of the structured detectors is very complex, however, so that the method for its production is also costly.

It is the object of the present invention to create a simplified scanning head, compared to the related art, for an optical position-measuring device that supplies signals that are as good as possible for position determination.

This object is attained by a device having the features of Claim 1. Advantageous specific embodiments are derived from the features delineated in the claims dependent on Claim 1.

A scanning head is described for an optical position-measuring system having a receiving grating formed of photosensitive areas, for scanning locally intensity-modulated light of different phase positions. The receiving grating is formed from a semiconductor layer stack, made up of a doped p-layer, an intrinsic i-layer and a doped n-layer. The individual photosensitive areas have a first doped layer and at least one part of the intrinsic layer in common, and are separated electrically from one another by interruptions in the second doped layer.

For, it was understood, on the one hand, that even the separation of only one of the doped layers leads to a sufficient electrical separation of the individual photosensitive areas. A cross feed, that is a disadvantage for the purposes of position determination, between areas of a different phase position does not appear any more, even at very slight distances of the individual areas with respect to one another.

On the other hand, such a layer construction also avoids another problem described in the related art. For, if the photosensitive areas are separated also by separating the intrinsic layer (and possibly also the second doped layer), deep trenches are formed which are managed only with difficulty in etching technology. Etching defects in the region of the intrinsic layer are also able to effect defects in the semiconductor material, whereby the photoelectric properties of the individual photosensitive areas are influenced in a very negative manner.

Amorphous silicon is particularly suitable as semiconductor material, but semiconductor layer stacks are also conceivable which totally or partly contain microcrystalline silicon.

Additional features, such as the positioning of the transmitting grating in the center of area of the receiving grating, an approximately elliptical or oval shape of the receiving grating, which has a greater extension perpendicular to the measuring direction than parallel to it, as well as the obtaining of phase-shifted signals from, in each case, a single period of the modulated light at the receiving grating lead to an optimization of the obtained scanning signals, and thus to an improved interpolation capability, and thus, finally to a higher resolution of the optical position-measuring system.

The design of the scanning head, and especially of the receiving grating with its photosensitive areas, permits in an elegant manner such optimizations in the layout of the structured detectors.

Further advantages of the present invention and details pertaining thereto are derived from the following description

of preferred specific embodiments, on the basis of the figures. In this context, the figures show:

Figures 1 a/b/c   an optical position-measuring unit,

Figures 2a/b/c/d/e embodiments of a dual field sensor, and

Figures 3a/b/c/d   embodiments of a single field sensor.

Figure 1a shows a scale 2, which carries an optical grating on a substrate 2.1, which is here also to be designated as scale graduation 2.2. Such a scale graduation 2.2 is able to exist, for example, as an amplitude grating having opaque crosspieces made of chromium and light transmitting gaps in the chromium coating. In this context, substrate 2.1 may be developed to be light-transmitting or, as in the case shown, reflecting. Other scales 2 are also able to have a phase grating or a combination of phase grating and amplitude grating.

Positioned opposite to the scale is a scanning head 1. scanning head 1 includes a light source 1.6, whose light falls, via a transmitting grating 1.5, on scale 2, is reflected there and redirected to scanning head 1. After the interaction with transmitting grating 1.5 and scale grating 2.2, the light has a local intensity pattern having a regular period. This intensity pattern is detected using a receiving grating 1.7 having a scale division T. In this context, receiving grating 1.7 itself is used as a patterned photodetector for detecting the intensity pattern.

For, receiving grating 1.7 has a patterned semiconductor layer stack 1.2 which converts incident light to electric current. In this context, the more current that is generated, the more the light that falls on semiconductor layer stack 1.2.

Figure 1b shows an enlarged section of Figure 1a. One may see substrate 1.1, on which a transparent electrode 1.3 is situated which, in turn, carries semiconductor layer stack 1.2. In the sequence of the passage of the light, the latter has a first doped (p-doped, in this case) layer 1.2.1 (p-layer), then an intrinsic layer 1.2.2 (i-layer), and finally a second doped (n-doped, in this case) layer 1.2.3 (n-layer). An electrical bottom contact follows n-layer 1.2.3. In principle, p-layer 1.2.1 and the n-layer could be exchanged, but the construction shown in Figure 1b is preferred.

The photosensitive areas forming receiving grating 1.7 are separated from one another in that n-layer 1.2.3 having bottom contacts 1.4 are interrupted where a separation of the individual photosensitive areas for detecting the intensity pattern are provided. Only in the region of bottom contacts 1.4 is current generated in semiconductor layer stack 1.2 in response to illumination, and so bottom contacting 1.4 defines receiving grating 1.7.

As may be seen in Figure 1b, the patterning of bottom contacting 1.4 and n-layer 1.2.3 is able to take place in a single lithography step and an etching step each for bottom contacts 1.4 and semiconductor layer stack 1.2. As the etching method for semiconductor layer stack 1.2, wet etching methods (e.g. KOH solution), but preferably dry etching methods (e.g. RIE using CHF_3) come into consideration. Such methods are widespread in microelectronics, and are therefore available without any problem.

Figure 1c, another section enlargement of Figure 1b, shows a detail of semiconductor layer stack 1.2. In order to be sure that n-layer 1.2.3 is completely interrupted (this is an absolutely necessary requirement, in order to separate the

individual photosensitive areas), it is necessary to set the etching process in such a way that at least a small part of i-layer 1.2.2 is also removed. On the other hand, at least a small part of i-layer 1.2.2 must be left standing, in order to be certain to prevent an electrical connection between p-layer 1.2.1 and n-layer 1.2.3

The layer construction in the region of receiving grating 1.7 could also look as follows: A layer of ZnO:Al of 0.3 - 1 μm thickness is applied to a glass substrate 1.1 of ca. 1 millimeter thickness, which is well suited to be transparent electrode 1.3. There follows semiconductor layer stack 1.2 having a p-layer 1.2.1 of ca. 10 nm, an i-layer 1.2.2 of ca. 400 nm, and an n-layer 1.2.3 of ca. 20 nm thickness. Bottom contacts 1.4 are made up of a metallic layer of a ca. 80 nm thickness, for instance, of chromium or aluminum. This metallic layer, in common with n-layer 1.2.3, is completely removed at suitable places for separating the individual photosensitive areas.

Because of the etching process used for separating the photosensitive areas, i-layer 1.2.2 is also taken down by ca. 40 nm, in order to achieve as certain a separation of n-layers 1.2.3 as possible. This is necessary, since the individual layers are not completely homogeneous with respect to their thickness, and besides, there is no sharply limited transition in the doping profile of semiconductor layer stack 1.2, especially between i-layer 1.2.2 and n-layer 1.2.3. In this connection, it is to be expected that, between photosensitive areas 3, a residual thickness of 5%-95%, better 10%-90% of the original thickness of i-layer 1.2.2 leads to good results. From a manufacturing technology point of view, since shorter etching times are to be preferred, and at greater residual thicknesses of i-layer 1.2.2 problems dealing with defects at the laid-bare edge of i-layer 1.2.2 are avoided, then, in the

ranges stated, the upper boundaries (that is, ca. 95% or ca 90%) are to be preferred. For the named layer thickness of 400 nm within photosensitive areas 3, a residual thickness of ca. 360 nm for i-layer 1.2.2 is thus regarded as being optimal.

Let us have a look now at what distance apart the individual photosensitive areas have to be positioned in order to receive the desired phase-shifted signals. This distance corresponds to scale division T of receiving grating 1.7. Let the period of the intensity pattern of the light irradiating receiving grating 1.7 be P. In scanning heads 1 having photosensitive areas developed as receiving grating 1.7, because of the danger of cross feed between the photosensitive areas, scale division T has to be selected to be greater than period P. If four signals phase-shifted by 90 degrees are desired, the following must apply

$T = (2 * n - 1) * 1/4 * P$ (n is an integer greater than or equal to three).

For a period P = 40 μm of the intensity pattern of the irradiated light, there thus comes about a scale division T of at least 50 μm. The individual phase-shifted signals are therefore gathered from four different periods of the intensity pattern, and thus also from different ranges of scale graduation 2.2. Therefore, let us designate this type of patterned detector as a four field sensor. It has the disadvantage that contamination on the scale take effect on phase-shifted signals not at the same time, but offset in phase. This results in inaccuracies during the evaluation of the phase-shifted signals.

Therefore, it is better to scan phase-shifted signals within a period P of the intensity pattern at receiving grating 1.7.

One possibility for this is represented by the dual field sensor, shown in Figures 2a-2e.

Photosensitive areas 3 are schematically seen in Figure 2a, whose design has already been shown in detail in Figures 1a-1c. These photosensitive areas are situated on substrate 1.1. Intensity pattern L having period P is schematically shown, and so is measuring direction M. One may see that, now within one period P, both a 0 degree signal and a 180 degree signal is able to be picked off. Adjacent photosensitive areas supply 180 degree phase-shifted signals if scale division T of receiving grating 1.7 corresponds to one-half of period P of incident, locally modulated intensity pattern L.

The following applies:

T= 1/2 * P.

Consequently, contamination on scale 2 will have an effect on both phase-shifted signals.

Figure 2b shows how photosensitive areas 3 are able to be connected to one another by printed conductors 4, in order to combine several 0 degree signals and several 180 degree signals to a stronger output signal. In this context, a comb structure is created in each case. These comb structures intermesh, so that in each case photosensitive areas 3 for 0 degree signals and photosensitive areas 3 for 180 degree signals alternate. As may be seen in Figure 2b, such a structure may be produced without crossed-over printed conductors.

Figure 2c shows how, using four comb structures, of which in each case two are interleaved according to Figure 2b, four signals may be gathered that are phase-shifted by 90 degrees

in each case. However, since two different ranges of the intensity pattern are scanned at receiving grating 1.7, one would call this a dual field sensor.

Figure 2d shows an especially advantageous design of such a scanning head 1 having a dual field sensor. Transmitting grating 1.5 is situated at the center of the dual field sensor. By "center", the center of area of receiving grating 1.7 is to be understood. Quadratic transmitting grating 1.5, in this context, is completely surrounded by receiving grating 1.7, in order to utilize as well as possible intensity pattern L. The grating lines of transmitting grating 1.5 and receiving grating 1.7 are perpendicular to measuring direction M. Receiving grating 1.4 is subdivided into four areas. Of the two inner areas, which border directly on transmitting grating 1.5, one is used for gathering 0 degree/180 degree signals, and the other of the two for gathering 90 degree/270 degree signals. An additional 90 degree/270 degree area, facing away from transmitting grating 1.5, borders on the inner 0 degree/180 degree area. An additional 0 degree/180 degree area, facing away from transmitting grating 1.5, borders on the inner 90 degree/270 degree area. This arrangement antisymmetric to the measuring direction makes certain that the four phase-shifted signals are picked up at comparable intensities.

The outer shape of entire receiving grating 1.7, that is composed of the four areas mentioned, as a rectangle having beveled corners, is approximated to an oval or an ellipse, whose greater diameter is perpendicular to measuring direction M. Such a shape permits an especially good utilization of intensity pattern L at receiving grating 1.7.

The four different areas of receiving grating 1.7 according to Figure 2d are constructed by interleaved comb structures

according to Figure 2c. A cutout enlargement of Figure 2d in Figure 2e makes this clear. This dual field sensor, which has proven very suitable in practice, may also therefore be produced without crossed-over printed conductors, which keeps the production process simple: Only one single metallization plane is required. With their patterning, photosensitive areas 3 are specified at the same time.

The dual field sensor described has the advantage that the amplitudes of the 0 degree/180 degree signals and the amplitudes of the 90 degree/270 degree signals are affected by possible contaminations simultaneously, and therewith in-phase. This reduces the scanning ratio error and increases the accuracy of the position determination as compared to a four field sensor. However, it is not the case, that all amplitudes of the four phase-shifted signals are impaired in-phase by contamination, so that the scanning is able to be further improved.

One obtains further improved signals from a scanning head 1 denoted here as a single field sensor. It is shown in Figure 3a that, in such a single field sensor, in each case four phase-shifted signals are obtained from one single period P of intensity pattern L. Adjacent photosensitive areas supply 90 degree phase-shifted signals if scale division T of receiving grating 1.7 corresponds to one-quarter of period P of incident, locally modulated intensity pattern L. The following equation applies:

$$T= 1/4 * P.$$

From the view in Figure 3b one may see that such a single field sensor can no longer do without crossed-over printed conductors. For, photosensitive areas 3 do carry a bottom contact 1.4 on their reverse side, which is allowed to be

connected to the printed conductors only at certain locations, using contactings 5. Between photosensitive areas 3 and printed conductors 4, an insulating layer thus has to be brought in which is only interrupted at contactings 5. Contacting 5 is simply formed by printed conductors 4 coming into contact directly with bottom contacts 1.4, when the metal layer forming printed conductors 4 is deposited.

It has been shown that, for a semiconductor layer stack 1.2 having the design described herein, a separation distance A of 5 μm is certainly sufficient to avoid cross feed between the individual photosensitive areas 3. However, depending on the detector geometry and the semiconductor material, even shorter distances A in the μm range are able to lead to functional scanning heads 1. The minimum distance A is essentially determined by the diffusion length of the charge carrier in i-layer 1.2.2. The shorter this diffusion length is, the shorter can distance A be. If we assume a diffusion length of 50 nm for amorphous silicon, then no more cross feed should occur at a distance A of ca. 200 nm. However, since for technical process reasons (increasing expenditure and rising sensitivity to defects for smaller structures) greater distances A are to be preferred, it may be stated that a meaningful lower boundary for distance A would be ca. 1 μm.

For a period P = 40 μm of the intensity-modulated light, for the four field sensor there comes about a scale division T of receiving grating 1.7 of 10 μm. Thus, at a distance A = 5 μm, photosensitive areas 3 themselves are down to only 5 μm.

Figure 3c shows a specific embodiment of such a single field sensor. Again, a transmitting grating 1.5 is situated in the center, or rather center of area, of receiving grating 1.7. Receiving grating 1.7, whose line direction, same as that of transmitting grating 1.5, again runs perpendicular to

measuring direction M, has an outer shape approximating an ellipse, whose greater diameter is perpendicular to measuring direction M. In the same way as in Figure 3b, receiving grating 1.7 is connected to printed conductors 4 that lie transversely across receiving grating 1.7. Respectively four such printed conductors 4 are situated on both sides of transmitting grating 1.5, so that they are also able to contact completely photosensitive areas 3 that are interrupted by transmitting grating 1.5.

Figure 3d shows one variant of the contacting of photosensitive areas 3 that is to be recommended as an alternative, and especially so for small scale divisions T of receiving grating 1.7 of the single field sensor. At the edge of receiving grating 1.7, grating lines having enlargements are provided. Since every other grating line is lengthened, it is possible to make these enlargements twice as wide as the grating lines themselves. This greatly simplifies the contacting of photosensitive areas 3 with printed conductors 4 via contactings 5. Again, it may be seen that such a single field sensor cannot be produced without crossover printed conductors 4.

It should still be mentioned that transmitting grating 1.5 preferably has the same layer construction as photosensitive areas 3. Since edges that are as sharply defined as possible are desirable for transmitting grating 1.5, semiconductor layer stack 1.2 is completely etched through in this region. However, it is also possible to develop transmitting grating 1.5 only as a patterned metal layer directly on substrate 1.1, in the usual manner. In both cases it is possible to perform the patterning of transmitting grating 1.5 and photosensitive areas 3 using the same lithography step.